W0224-001A
APOLLO CRADLES LTD
1.5M X-BEAM 2016
DESIGN CHECK CALCULATIONS

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Document Revision History

Revision	Description	Author	Revision Date	Checked
A	Initial Issue	MRB	07/12/2016	MMR

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			ALAN WHITE DESIGN
	Element :	Brief			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Brief

The brief is to prepare calculated values for the capacity of the Apollo 1.5m X-Beam to BS EN 1999-1-1.

The beams are manufactured from tube extrusions in aluminium alloy 6082 T6.

Alloy

The alloy used is 6082 T6:

For extruded profiles/tubes with thickness less than 5mm:

$P_{o,haz}$ =	0.50	
$P_{u,haz}$ =	0.64	
F_o =	250	N/mm^2
F_u =	290	N/mm^2

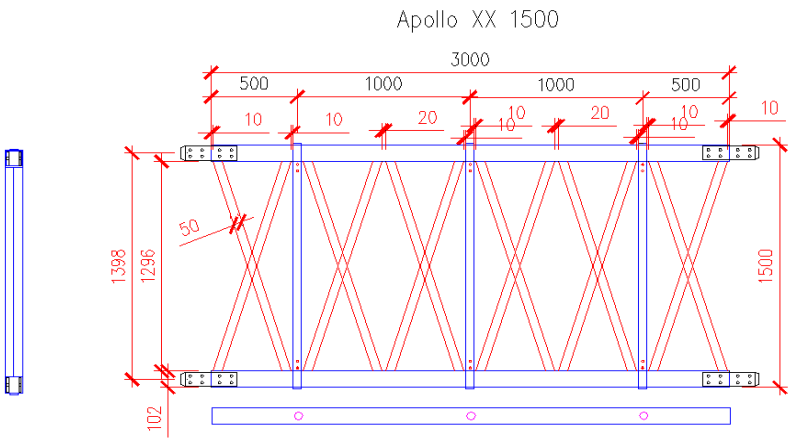
For extruded profiles/tubes with thickness greater than 5mm:

$P_{o,haz}$ =	0.48	
$P_{u,haz}$ =	0.60	
F_o =	260	N/mm^2
F_u =	310	N/mm^2

Layout

All beam lengths define the overall length of beam and not the span. As the beam is supported at the verticals, all spans are 1m less than the beam length.

The geometry of the beam is shown in the drawing below:



Design

Eurocode 9: Design of Aluminium structures EN 1999-1-1

Alloy used is 6082 T6 throughout

Design Assumptions

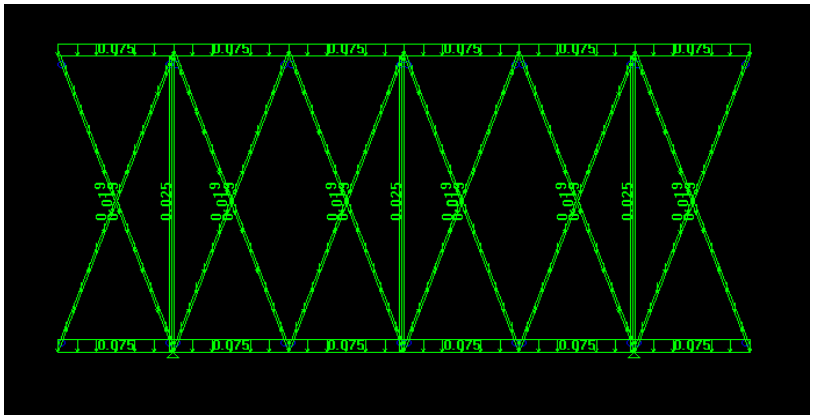
6082 T6 Aluminium is to be utilised throughout.

X-beam top and bottom booms are to be restrained at 1.00m c/c's.

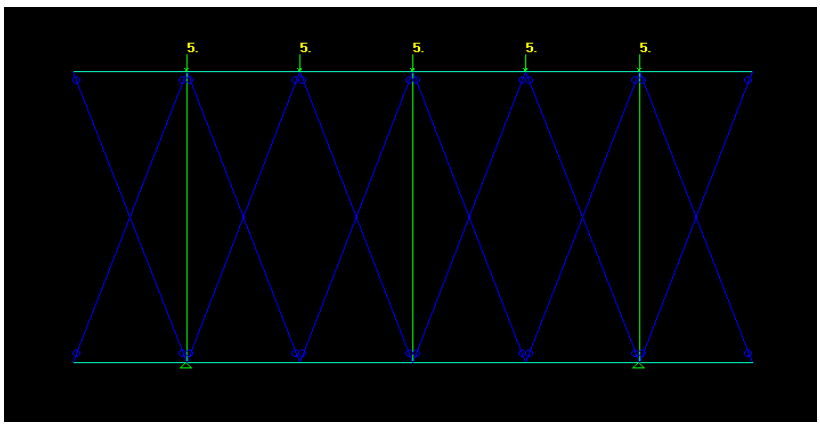
All loads are to be applied at node locations.

Load Cases **Images are shown for a 3m beam, loading for larger beams is applied using the same methodology.**

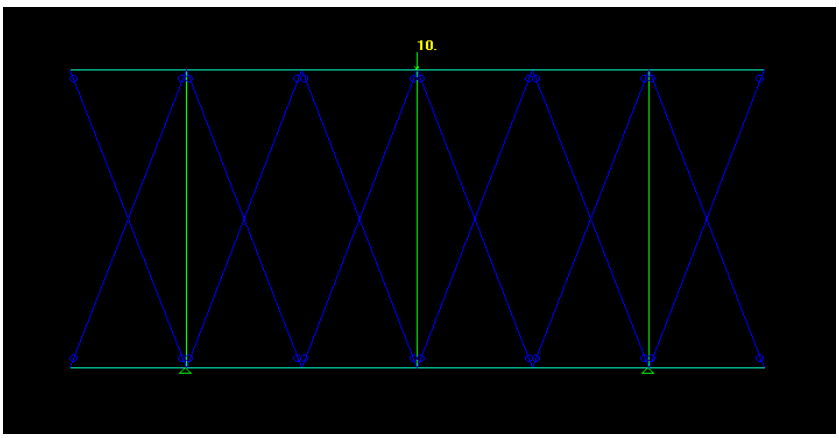
Load Case 1 Self Weight
Self weight of all members factored by 1.15 to account for connections



Load Case 2 UDL
10kN/m Load Applied to top boom over full length of the X-Beam at node points



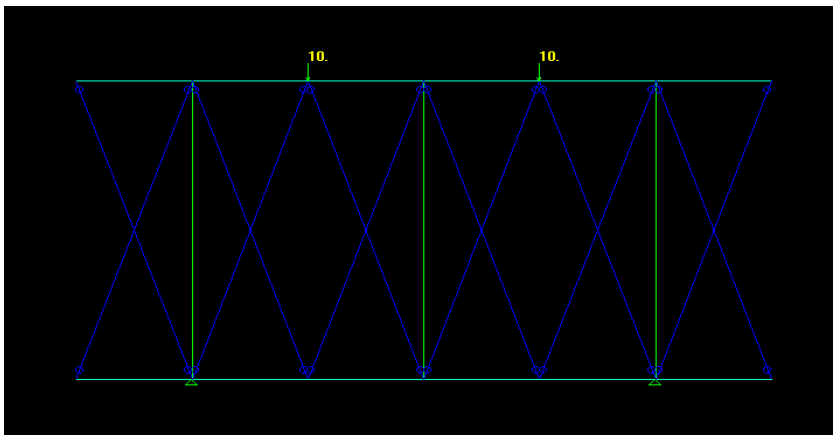
Load Case 3 Central Point Load
10kN Point Load Applied to Centre of Top Boom of the X-Beam



Load Case 4

Two Point Loads

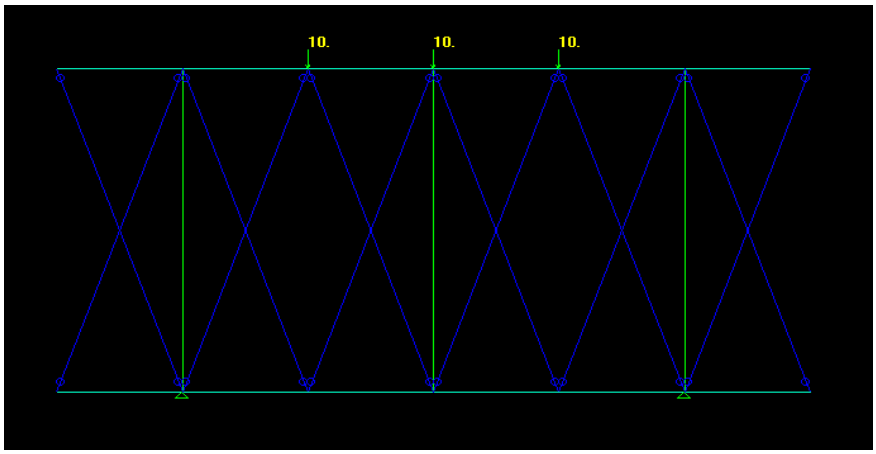
2No 10kN point loads applied at third points along the top boom of the X-Beam.



Load Case 5

Three Point Loads

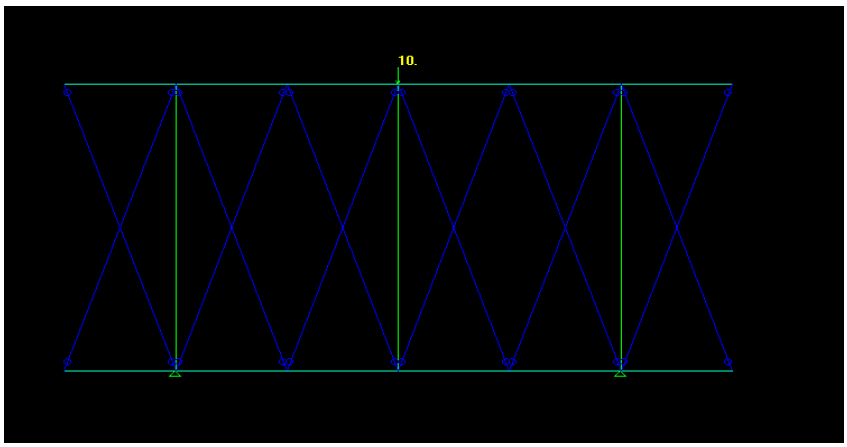
3No 10kN Point Loads applied at quarter points along the X-Beam



Load Case 6

End Shear

10kN Point Load applied 1.0m from support



Load Combinations

Combination Number	Combination Description	Load Cases
1	UDL	1+2
2	Central Point Load	1+3
3	Two Point Loads	1+4
4	Three Point Loads	1+5
5	End Shear	1+6

Above Combinations were checked for the following design factors:

γ_D= 1.35

γ_L= 1.50

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	Element :	Main Boom Capacity		
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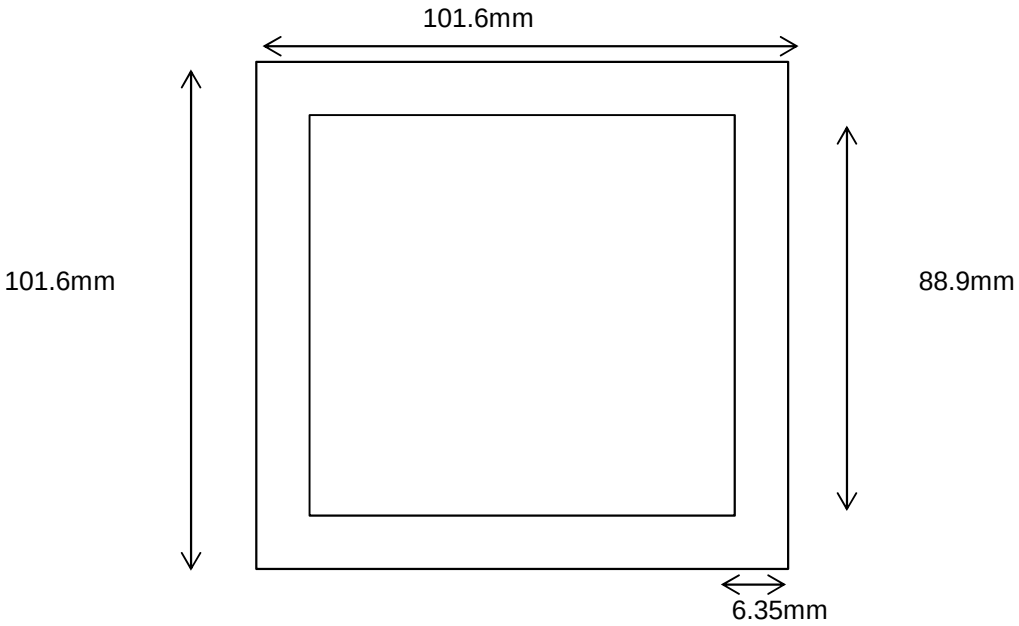
ALAN WHITE DESIGN

Main Boom Capacity

101.6 x 101.6 x 6.35mm SHS 6082-T2

Alu. 6082-T2	$P_{o,haz}$ =	0.48		(Table 3.2b)
	$P_{u,haz}$ =	0.60		
	f_o =	260	N/mm^2	
	f_u =	310	N/mm^2	



A=	2419	mm^2
I=	3674543	mm^4
W_{el}=	72334	mm^3
W_{pl}=	86800	mm^3
r_y=	38.97	mm

for slenderness	β=	b/t	b=	101.60	mm
	=	16.00	t =	6.35	mm
	ε=	sqrt(250/f_o)	f_o=	260	N/mm^2
	=	0.98			

Class A, without welds, Internal parts	β_1=	11ε
	=	11*0.98
	=	10.78
	<	16.00
	β_2=	16ε
	=	16*0.98
	=	15.68
	<	16.00

$\beta_3 = 22\varepsilon$

$= 22*0.98$

$= 21.56$

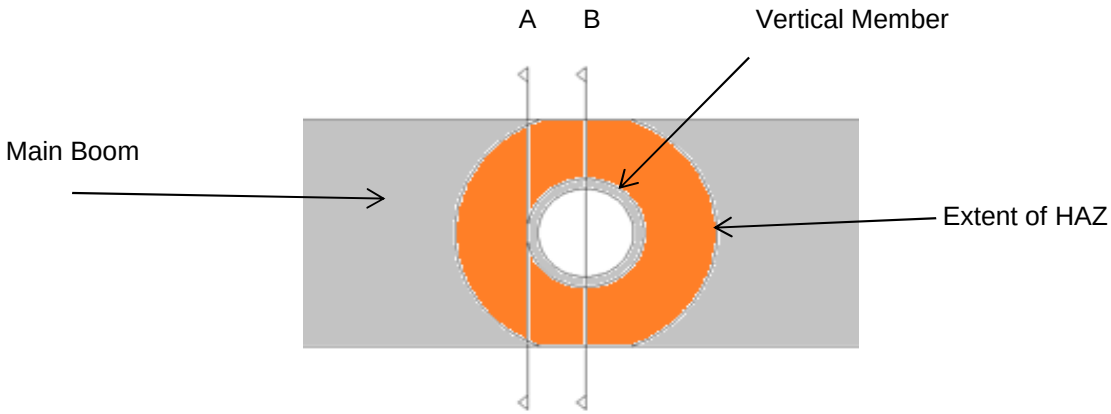
> 16.00

Section is class 3

Main Boom HAZ

There are HAZ's at welded joints to the diagonal and vertical.
HAZ Section at diagonal not considered as Vertical HAZ is more detrimental

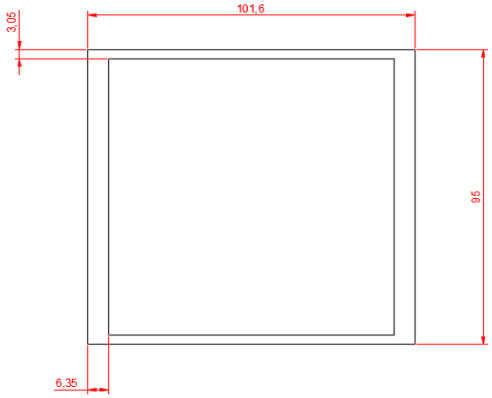
Two HAZ sections considered at the vertical, one at the edge of the vertical (A-A) and one through the mid-section of the vertical (B-B).



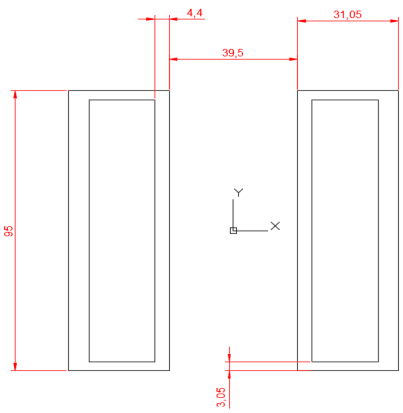
PLAN VIEW OF VERTICAL TO MAIN BOOM CONNECTION

Take sections shown below as heat affected

SHS $P_{o,haz}$ HAZ Section Layout



Section A-A

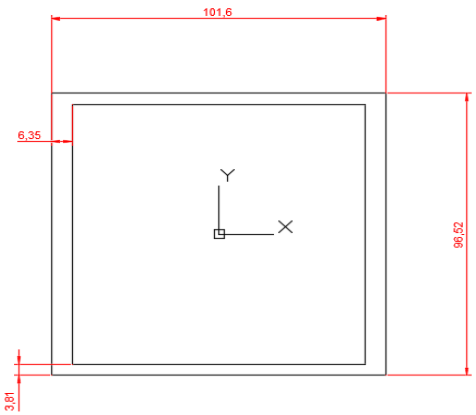


Section B-B

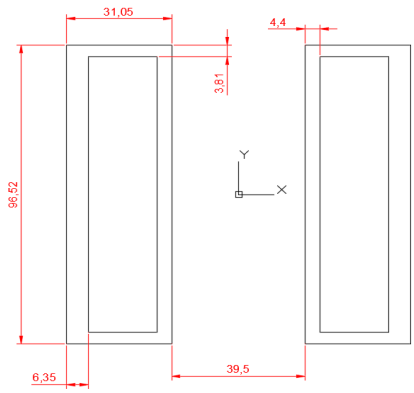
	A-A	B-B	
A=	**1748.0**	2290.2	mm^2
I=	**3097368.8**	3444575.0	mm^4
$W_{el,PoHAZ}$=	**65207.8**	72517.4	mm^3
$W_{pl,PoHAZ}$=	**78249.3**	87020.8	mm^3
r_y=	**42.1**	38.8	mm

Conservatively, use section A-A as HAZ section properties are lower.

SHS $P_{u,haz}$ HAZ Section Layout



Section A-A



Section B-B

	A-A	B-B	
A=	**1903.0**	2384.6	mm^2
I=	**3230562.0**	3569613.0	mm^4
$W_{el,PuHAZ}$=	**66940.8**	73966.3	mm^3
$W_{pl,PuHAZ}$=	**80328.9**	88759.5	mm^3
r_y=	**41.2**	38.7	mm

Conservatively, use section A-A as HAZ section properties are lower.

Boom SHS Moment Capacity (6.2.5.1)

Non-HAZ

$M_{o,Rd} = \alpha W_{el} f_o / \gamma_{M1}$

$\alpha_{3,u}$ =	1.00	(Table 6.4)
W_{el} =	72.33	cm^3
f_o =	260	N/mm^2
γ_{M1} =	1.1	(6.1.3)

= 1.00*72.33*260/1100

$M_{o,Rd}$ = 17.10 kNm

HAZ

$M_{u,Rd} = W_{net} f_u / \gamma_{M2}$

$W_{net} = W_{el,PuHAZ}$

$= 66.94\ cm^3$

$f_u = 310\ N/mm^2$

$\gamma_{M2} = 1.25$ (6.1.3)

$= 66.94*310/1250$

$M_{u,Rd} = 16.60\ kNm$

$M_{Rd,x} = 16.60\ kNm$ lesser value of $M_{c,Rd}$ / $M_{u,Rd}$

Boom SHS Shear Capacity (6.2.6)

$V_{Rd} = A_v f_o / \sqrt{3}\gamma_{M1}$

$A_v = 0.6A_e$

$A_v = 0.6*1748$

$A_v = 1{,}048.80\ mm^2$

$\gamma_{M1} = 1.1$

$f_o = 260\ N/mm^2$

$= 1048.80*260/(SQRT(3)*1100)$

$V_{Rd} = 143.12\ kN$

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ALAN WHITE DESIGN

Boom SHS Axial Comp Capacity @ 1000mm (effective length of beam between restraints)

Without Weld

$N_{b,Rd} = kX\omega_x A_{eff} f_o / \gamma_{M1}$ (6.3.1.1 (6.49a))

$N_{cr} = \pi^2 EI / k^2 L^2$ (Appendix I.3)

E = 70,000 N/mm^2
I = 3,674,543 mm^4
k = 0.50
L = 1,000 mm

N_{cr} = ((PI()^2)*70000*3674543)/((0.5^2)*(1000^2))
= 10,154,560.01 N

$\lambda = \sqrt{A_{eff} f_o / N_{cr}}$ (6.3.1.2)
= 0.25
A_{eff} = 2419 mm^2
A = 2,419 mm^2

$X = 1/ \Phi+\sqrt{\Phi^2-\lambda^2}$

$\Phi = 0.5(1+\acute{\alpha}(\lambda-\lambda_o)+\lambda^2)$
$\acute{\alpha}$ = 0.20 Table 6.6
λ_o = 0.10 Table 6.6
Φ = 0.55
X = 0.92

k= 1.00 (no welds)

ω_x= 1/(X+(1-X)sin(PI()x_s/lcr))

= 1.08

$N_{b,Rd}$ = 1.00*0.92*1.08*2419*260/1100
= 568.10 kN

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			AWD ALAN WHITE DESIGN
	Element :	Main Boom Capacity			
	Job Number :	W0224	By : mrb	Date: Dec 16	
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Localised Weld

$N_{b,Rd} = X_{haz}\omega_{x,haz} A_{u,eff} f_u / \gamma_{M2}$ (6.3.1.1 (6.49b))

$N_{cr} = \pi^2 EI / k^2 L^2$ (Appendix I.3)

$E =$ 70,000 N/mm^2
$I =$ 3,674,543 mm^4
$k =$ 0.50
$L =$ 1,000 mm

$N_{cr} =$ ((PI()^2)*70000*3674543)/((0.5^2)*(1000^2))
$=$ 10,154,560.01 N

$\lambda_{haz} = \sqrt{A_{u,eff} f_u / N_{cr}}$ (6.3.1.2)
$=$ 0.23

$A_{u,eff} =$ 1903 mm^2
$A =$ 2,419 mm^2

$X = 1/ \Phi+\sqrt{\Phi^2-\lambda^2}$

$\Phi = 0.5(1+\acute{\alpha}(\lambda-\lambda_o)+\lambda^2)$
$\acute{\alpha} =$ 0.20 Table 6.6
$\lambda_o =$ 0.10 Table 6.6
$\Phi =$ 0.54
$X =$ 0.94

$\omega_{x,haz} = 1/(X_{haz}+(1-X_{haz})\sin(PI()x_{s,haz}/lcr))$

$=$ 1.06

$N_{b,Rd} =$ 0.94*1.06*1903*310/1250
$=$ 470.25 kN

Lesser Value= 470.25 kN

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			ALAN WHITE DESIGN
	Element :	Main Boom Capacity			
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SHS Axial Tension Capacity (6.2.3)

1. General yielding

$N_{o,Rd} = A_g f_o / \gamma_{M1}$

$f_o =$ 260 N/mm^2

$A_g =$ A

$=$ 2419 mm^2

$\gamma_{M1} =$ 1.1

$=$ 2419*260/1100

$=$ 571.76 kN

2. Local failure

$N_{u,Rd} = A_{u,eff} f_u / \gamma_{M2}$

$f_u =$ 310 N/mm^2

$A_{u,eff} =$ 1903 mm^2

$\gamma_{M1} =$ 1.25

$=$ 1903*310/1250

$=$ 471.94 kN

Lesser Value= 471.94 kN

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			ALAN WHITE DESIGN
	Element :	Vertical CHS Member Capacity			
	Job Number :	W0224	By : mrb	Date: Dec 16	
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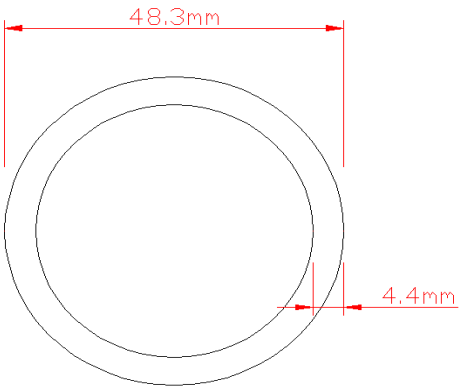
Vertical CHS Member Capacity
ø48.3mm x 4.4mm CHS 6082-T6

Alu. 6082-T2	$P_{o,haz}$ =	0.50		(Table 3.2b)
	$P_{u,haz}$ =	0.64		
	f_o =	250	N/mm^2	
	f_u =	290	N/mm^2	



Section Properties

		A=	607	mm^2	
		I=	147654	mm^4	
		W_{el}=	6114	mm^3	
		W_{pl}=	8254	mm^3	
		ry=	15.6	mm	
for slenderness	β=	b/t	b=	48.3	mm
	=	10.98	t =	4.4	mm
	ε=	sqrt(250/f_o)	f_o=	250	N/mm^2
	=	1.00			
Class A, without welds, Internal parts		β_1=	11ε		
		=	11*1.0		
		=	11.00		
		>	10.98		

Section is class 1

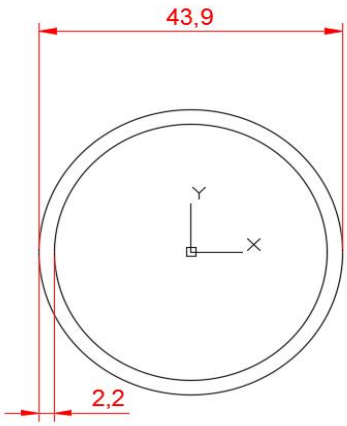
Vertical CHS HAZ Length

Full perimeter weld at the joint, therefore the entire section is affected by HAZ.

As per BS EN 1999-1-1, for HAZ wall thickness factored by 0.50 (For $P_{o,haz}$)

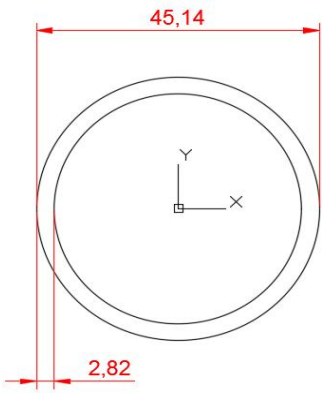
As per BS EN 1999-1-1, for HAZ wall thickness factored by 0.64 (For $P_{u,haz}$)

Vertical CHS $P_{o,haz}$ HAZ Section Layout



A_{haz}=	288	mm^2
I=	62820	mm^4
I_z=	62820	mm^4
$W_{el,PoHAZ}$=	2,862	mm^3
$W_{pl,PoHAZ}$=	3,864	mm^3

Vertical CHS $P_{u,haz}$ HAZ Section Layout



A_{haz}=	374	mm^2
I=	84308	mm^4
I_z=	84308	mm^4
$W_{el,PuHAZ}$=	3,735	mm^3
$W_{pl,PuHAZ}$=	5,043	mm^3

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016		
	Element :	Vertical CHS Member Capacity		
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ALAN WHITE DESIGN

Vertical CHS Moment Capacity (6.2.5.1)

Non-HAZ

$M_{o,Rd} = \alpha W_{el} f_o / \gamma_{M1}$

$\alpha = W_{pl}/W_{el}$ (Table 6.4)

$= 1.35$

$W_{el} = 6.11\ cm^3$

$f_o = 250\ N/mm^2$

$\gamma_{M1} = 1.1$ (6.1.3)

$= 1.35*6.11*250/1100$

$M_{o,Rd} = 1.87\ kNm$

HAZ

$M_{u,Rd} = W_{net} f_u / \gamma_{M2}$

$W_{net} = W_{el,PuHAZ}$

$= 3.74\ cm^3$

$f_u = 290\ N/mm^2$

$\gamma_{M2} = 1.25$ (6.1.3)

$= 3.74*290/1250$

$M_{u,Rd} = 0.87\ kNm$

$M_{Rd,x} = 0.87\ kNm$ lesser value of $M_{c,Rd}$ / $M_{u,Rd}$

Vertical CHS Shear Capacity (6.2.6)

$V_{Rd} = A_v f_o / \sqrt{3}\gamma_{M1}$

$A_v = 0.6A_e$

$A_v = 0.6*288$

$A_v = 172.80\ mm^2$

$\gamma_{M1} = 1.1$

$f_o = 250\ N/mm^2$

$= 172.80*250/(SQRT(3)*1100)$

$V_{Rd} = 22.67\ kN$

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ALAN WHITE DESIGN

Vertical CHS Axial Comp Capacity @ 1297mm (effective length of beam)

Without Weld

$N_{b,Rd} = kX\omega_x A_{eff} f_o / \gamma_{M1}$ (6.3.1.1 (6.49a))

$N_{cr} = \pi^2 EI / k^2 L^2$ (Appendix I.3)

E = 70,000 N/mm^2
I = 147,654 mm^4
k = 0.50
L = 1,297 mm

N_{cr} = ((PI()^2)*70000*147654)/((0.5^2)*(1297^2))
= 242,562.15 N

$\lambda = \sqrt{A_{eff} f_o / N_{cr}}$ (6.3.1.2)
= 0.79
A_{eff} = 607 mm^2
A = 607 mm^2

$X = 1/ \Phi+\sqrt{\Phi^2-\lambda^2}$

$\Phi = 0.5(1+\acute{\alpha}(\lambda-\lambda_o)+\lambda^2)$
$\acute{\alpha}$ = 0.20 Table 6.6
λ_o = 0.10 Table 6.6
Φ = 0.88
X = 0.57

k= 1.00 (no welds)

ω_x= 1/(X+(1-X)sin(PI()x_s/lcr))

= 1.69

$N_{b,Rd}$ = 1.00*0.57*1.69*607*250/1100
= 132.89 kN

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ALAN WHITE DESIGN

Localised Weld

$N_{b,Rd} = X_{haz}\omega_{x,haz} A_{u,eff} f_u / \gamma_{M2}$ (6.3.1.1 (6.49b))

$N_{cr} = \pi^2 EI / k^2 L^2$ (Appendix I.3)

$E =$ 70,000 N/mm^2

$I =$ 147,654 mm^4

$k =$ 0.50

$L =$ 1,297 mm

$N_{cr} =$ ((PI()^2)*70000*147654)/((0.5^2)*(1297^2))

$=$ 242,562.15 N

$\lambda_{haz} = \sqrt{A_{u,eff} f_u / N_{cr}}$ (6.3.1.2)

$=$ 0.63

$A_{u,eff} =$ 374 mm^2

$A =$ 607 mm^2

$X = 1/ \Phi+\sqrt{\Phi^2-\lambda^2}$

$\Phi = 0.5(1+\acute{\alpha}(\lambda-\lambda_o)+\lambda^2)$

$\acute{\alpha} =$ 0.20 Table 6.6

$\lambda_o =$ 0.10 Table 6.6

$\Phi =$ 0.75

$X =$ 0.67

$\omega_{x,haz} = 1/(X_{haz}+(1-X_{haz})\sin(PI()x_{s,haz}/lcr))$

$=$ 1.45

$N_{b,Rd} =$ 0.67*1.45*374*290/1250

$=$ 84.30 kN

Lesser Value= 84.30 kN

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ALAN WHITE DESIGN

Vertical CHS Axial Tension Capacity (6.2.3)

1. General yielding

$N_{o,Rd} = A_g f_o / \gamma_{M1}$

$f_o =$ 250 N/mm^2

$A_g =$ A

$=$ 607 mm^2

$\gamma_{M1} =$ 1.1

$=$ 607*250/1100

$=$ 137.95 kN

2. Local failure

$N_{u,Rd} = A_{u,eff} f_u / \gamma_{M2}$

$f_u =$ 290 N/mm^2

$A_{u,eff} =$ 374 mm^2

$\gamma_{M1} =$ 1.25

$=$ 374*290/1250

$=$ 86.77 kN

Lesser Value= 86.77 kN

SHS Diagonal Layout

50.8 x 50.8 x 3mm SHS 6082-T2

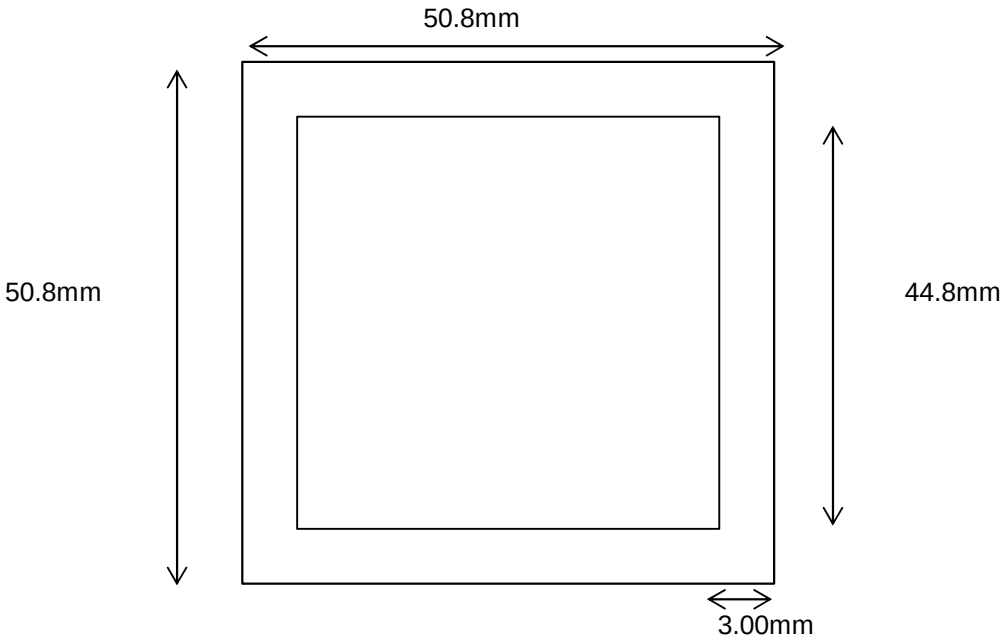
Alu. 6082-T2

$P_{o,haz}$ = 0.50 (Table 3.2b)

$P_{u,haz}$ = 0.64

f_o = 250 N/mm^2

f_u = 290 N/mm^2



A= 574 mm^2

I= 219291 mm^4

W_{el}= 8634 mm^3

W_{pl}= 10360 mm^3

r_y= 19.55 mm

for slenderness

β= b/t b= 50.80 mm

= 16.93 t = 3.00 mm

ε= sqrt(250/f_o) f_o= 250 N/mm^2

= 1.00

Class A, without welds, Internal parts

β_1= 11ε

= 11*1.00

= 11.00

< 16.93

β_2= 16ε

= 16*1.00

= 16.00

< 16.93

$\beta_3 = 22\varepsilon$

$= 22*1.00$

$= 22.00$

> 16.93

Section is class 3

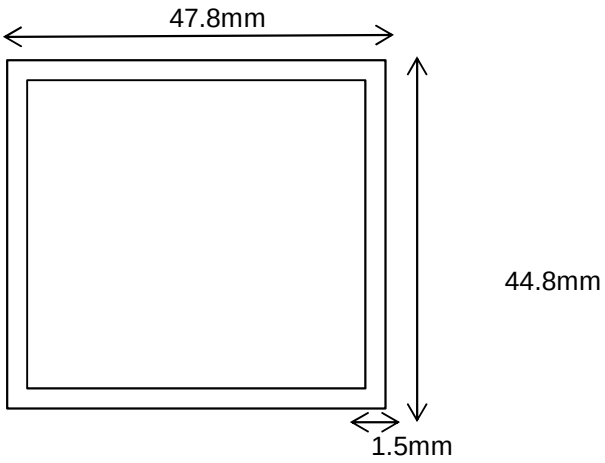
SHS Diagonal HAZ Length

Full perimeter weld at the joint, therefore the entire section is affected by HAZ.

As per BS EN 1999-1-1, for HAZ wall thickness factored by 0.50 (For $P_{o,haz}$)

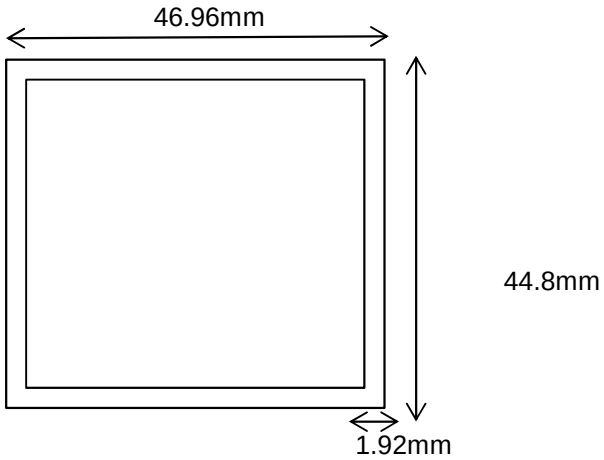
As per BS EN 1999-1-1, for HAZ wall thickness factored by 0.64 (For $P_{u,haz}$)

SHS Diagonal $P_{o,haz}$ HAZ Section Layout



A_{haz}=	278	mm^2
I=	99357	mm^4
I_z=	99357	mm^4
$W_{el,PoHAZ}$=	4,157	mm^3
$W_{pl,PoHAZ}$=	4,989	mm^3

SHS Diagonal $P_{u,haz}$ HAZ Section Layout



A_{haz}=	358	mm^2
I=	130752	mm^4
I_z=	130752	mm^4
$W_{el,PuHAZ}$=	5,376	mm^3
$W_{pl,PuHAZ}$=	6,452	mm^3

SHS Diagonal Axial Tension Capacity (6.2.3)

1. General yielding

$N_{o,Rd} = A_g f_o / \gamma_{M1}$

f_o =	250	N/mm^2
A_g =	A	
=	574	mm^2
γ_{M1} =	1.1	

= 574*250/1100
= 130.45 kN

2. Local failure

$N_{u,Rd} = A_{u,eff} f_u / \gamma_{M2}$

f_u =	290	N/mm^2
$A_{u,eff}$ =	358	mm^2
γ_{M1} =	1.25	

= 358*290/1250
= 83.06 kN

Lesser Value= 83.06 kN

SHS Diagonal Axial Comp Capacity @ 732mm (effective length of beam)

Without Weld

$N_{b,Rd} = kX\omega_x A_{eff} f_o / \gamma_{M1}$ (6.3.1.1 (6.49a))

$N_{cr} = \pi^2 EI / k^2 L^2$ (Appendix I.3)

$E =$ 70,000 N/mm^2

$I =$ 219,291 mm^4

$k =$ 0.50

$L =$ 732 mm

$N_{cr} =$ ((PI()^2)*70000*219291)/((0.5^2)*(732^2))

$=$ 1,130,983.90 N

$\lambda = \sqrt{A_{eff} f_o / N_{cr}}$ (6.3.1.2)

$=$ 0.36 $A_{eff} =$ 574 mm^2

$A =$ 574 mm^2

$X = 1/ \Phi+\sqrt{\Phi^2-\lambda^2}$

$\Phi = 0.5(1+\acute{\alpha}(\lambda-\lambda_o)+\lambda^2)$

$\acute{\alpha} =$ 0.20 Table 6.6

$\lambda_o =$ 0.10 Table 6.6

$\Phi =$ 0.59

$X =$ 0.86

$k =$ 1.00 (no welds)

$\omega_x = 1/(X+(1-X)\sin(PI()x_s/lcr))$

$=$ 1.16

$N_{b,Rd} =$ 1.00*0.86*1.16*574*250/1100

$=$ 130.14 kN

Localised Weld

$N_{b,Rd} = X_{haz}\omega_{x,haz} A_{u,eff} f_u / \gamma_{M2}$ (6.3.1.1 (6.49b))

$N_{cr} = \pi^2 EI / k^2 L^2$ (Appendix I.3)

E = 70,000 N/mm^2
I = 219,291 mm^4
k = 0.50
L = 732 mm

N_{cr} = ((PI()^2)*70000*219291)/((0.5^2)*(732^2))
= 1,130,983.90 N

$\lambda_{haz} = \sqrt{A_{u,eff} f_u / N_{cr}}$ (6.3.1.2)
= 0.28

$A_{u,eff}$ = 358 mm^2
A = 574 mm^2

$X = 1/ \Phi+\sqrt{\Phi^2-\lambda^2}$

$\Phi = 0.5(1+\acute{\alpha}(\lambda-\lambda_o)+\lambda^2)$
$\acute{\alpha}$ = 0.20 Table 6.6
λ_o = 0.10 Table 6.6
Φ = 0.56
X = 0.90

$\omega_{x,haz} = 1/(X_{haz}+(1-X_{haz})\sin(PI()x_{s,haz}/lcr))$

= 1.10

$N_{b,Rd}$ = 0.90*1.10*358*290/1250
= 82.23 kN

Lesser Value= 82.23 kN

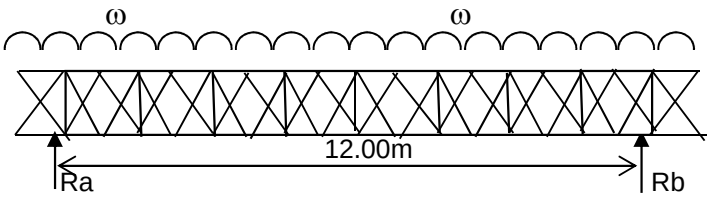
CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			AWD ALAN WHITE DESIGN
	Element :	12m X-Beam Results			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

12m X-Beam Results

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			ALAN WHITE DESIGN
	Element :	12m X-Beam Load Combination 1			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Load Comb. 1 UDL load 10kN/m applied along beam

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	3.72	4.47
	Shear	V_{Rd}	143.12	9.77	14.66
	Tension	$N_{o,Rd}$	471.94	54.37	8.68
	Compression	$N_{b,Rd}$	470.25	164.18	2.86
	Deflection	d	120.00	17.80	6.74
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	1.89
Vertical	Moment	$M_{c,Rd}$	0.87	0.13	6.89
	Shear	V_{Rd}	22.67	0.18	128.83
	Tension	$N_{o,Rd}$	86.77	0.75	115.85
	Compression	$N_{b,Rd}$	84.30	25.07	3.36
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	2.43
Diagonal	Tension	$N_{o,Rd}$	83.06	38.11	2.18
	Compression	$N_{b,Rd}$	82.23	49.46	1.66
				Factor	**1.66**



Max Moment= $WL^2/8$

so for ultimate condition

W= 1.5*10
15.00 kN

apply factor from above

Wf= 15*1.66
= 24.90 kN

so maximum moment is as above

Ultimate Mu= Wf*12^2/8
= (24.90*12^2)/8
= 448.20 kNm

and for allowable value

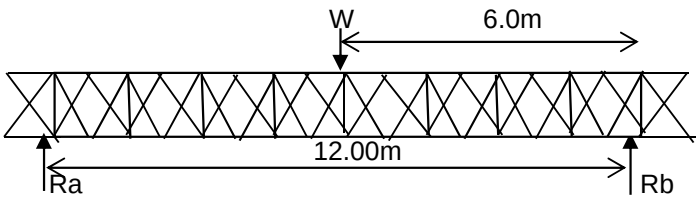
allowable max moment= 448.20/1.50
= 298.80 kNm

Moment values	**Ultimate**	**448.20 kNm**
	Allowable	**298.80 kNm**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			ALAN WHITE DESIGN
	Element :	12m X-Beam Load Combination 2			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Load Comb. 2 Point load 10kN load applied at midspan of beam

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	0.80	20.67
	Shear	V_{Rd}	143.12	2.03	70.64
	Tension	$N_{o,Rd}$	471.94	15.20	31.05
	Compression	$N_{b,Rd}$	470.25	30.73	15.30
	Deflection	d	120.00	3.34	35.93
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	9.58
Vertical	Moment	$M_{c,Rd}$	0.87	0.02	51.04
	Shear	V_{Rd}	22.67	0.02	985.83
	Tension	$N_{o,Rd}$	86.77	0.53	165.27
	Compression	$N_{b,Rd}$	84.30	2.52	33.48
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	21.94
Diagonal	Tension	$N_{o,Rd}$	83.06	4.99	16.64
	Compression	$N_{b,Rd}$	82.23	5.90	13.95
				Factor	**9.58**



Max Moment= WL/4

so for ultimate condition

W= 1.50*10
= 15.00 kN

apply factor from above

Wf= 15*9.58
= 143.70 kN

so maximum moment is as above

Ultimate Mu= Wf*L/4
= 143.70*12/4
= 431.10 kNm

and for allowable value

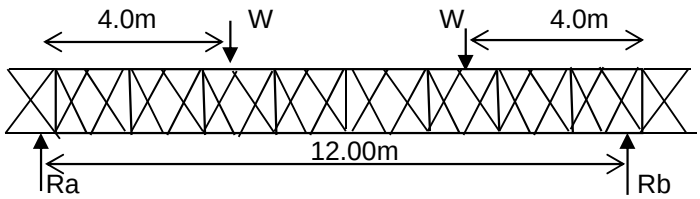
allowable max moment= 431.10/1.50
= 287.40 kNm

Moment values	**Ultimate**	**431.10 kNm**
	Allowable	**287.40 kNm**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			ALAN WHITE DESIGN
	Element :	12m X-Beam Load Combination 3			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Load Comb. 3 PL at third points 10kN load applied at each of the two third points

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	0.80	20.73
	Shear	V_{Rd}	143.12	2.03	70.57
	Tension	$N_{o,Rd}$	471.94	13.03	36.22
	Compression	$N_{b,Rd}$	470.25	41.21	11.41
	Deflection	d	120.00	4.52	26.55
	Combined Axial	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	7.94
Vertical	Moment	$M_{c,Rd}$	0.87	0.03	27.12
	Shear	V_{Rd}	22.67	0.04	539.86
	Tension	$N_{o,Rd}$	86.77	0.63	138.83
	Compression	$N_{b,Rd}$	84.30	4.48	18.80
	Combined Axial	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	12.07
Diagonal	Tension	$N_{o,Rd}$	83.06	9.06	9.17
	Compression	$N_{b,Rd}$	82.23	10.25	8.02
				Factor	**7.94**



Max Moment= WL/3

so for ultimate condition

W= 1.50*10
15.00 kN

apply factor from above

Wf= 15.00*7.94
= 119.10 kN

so maximum moment is as above

Ultimate Mu= Wf*L/3
= (119.10*12)/3
= 476.40 kNm

and for allowable value

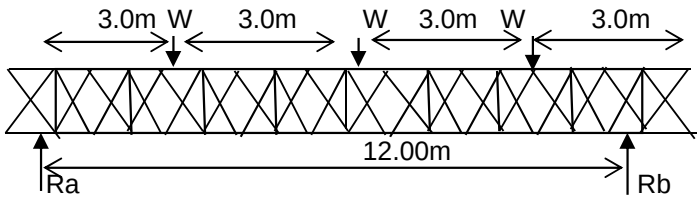
allowable max moment= 476.40/1.50
= 317.60 kNm

Moment values	**Ultimate**	**476.40 kNm**
	Allowable	**317.60 kNm**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			AWD ALAN WHITE DESIGN
	Element :	12m X-Beam Load Combination 4			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Load Comb. 4 Load at quarter points
10kN load applied at each of the three quarter points

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	1.07	15.46
	Shear	V_{Rd}	143.12	2.77	51.73
	Tension	$N_{o,Rd}$	471.94	21.12	22.35
	Compression	$N_{b,Rd}$	470.25	57.49	8.18
	Deflection	d	120.00	6.34	18.93
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	5.76
Vertical	Moment	$M_{c,Rd}$	0.87	0.05	18.86
	Shear	V_{Rd}	22.67	0.06	365.71
	Tension	$N_{o,Rd}$	86.77	0.73	119.02
	Compression	$N_{b,Rd}$	84.30	6.44	13.08
	Combined Axial	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	8.40
Diagonal	Tension	$N_{o,Rd}$	83.06	13.09	6.34
	Compression	$N_{b,Rd}$	82.23	14.41	5.71
				Factor	**5.71**



Max Moment= WL/2

so for ultimate condition

W= 1.50*10
15.00 kN

apply factor from above

Wf= 15.00*5.71
= 85.65 kN

so maximum moment is as above

Ultimate Mu= Wf*12/2
= (85.65*12)/2
= 513.90 kNm

and for allowable value

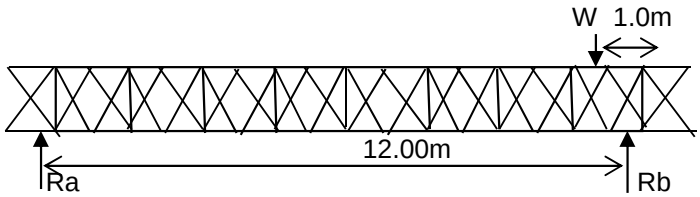
allowable max moment= 513.90/1.50
= 342.60 kNm

Moment values	**Ultimate**	**513.90 kNm**
	Allowable	**342.60 kNm**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			ALAN WHITE DESIGN
	Element :	12m X-Beam Load Combination 5			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Load Comb. 5 End Shear 10kN load applied at a 1.0m distance from the support

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	0.69	23.99
	Shear	V_{Rd}	143.12	2.04	70.30
	Tension	$N_{o,Rd}$	471.94	3.76	125.52
	Compression	$N_{b,Rd}$	470.25	11.06	42.51
	Deflection	d	120.00	1.08	111.11
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	16.88
Vertical	Moment	$M_{c,Rd}$	0.87	0.01	61.98
	Shear	V_{Rd}	22.67	0.02	1133.71
	Tension	$N_{o,Rd}$	86.77	0.24	364.57
	Compression	$N_{b,Rd}$	84.30	4.05	20.81
	Combined Axial	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	16.50
Diagonal	Tension	$N_{o,Rd}$	83.06	6.25	13.29
	Compression	$N_{b,Rd}$	82.23	7.74	10.62
				Factor	**10.62**



Max Shear Rb= W*11/12

so for ultimate condition

W= 1.50*10
15.00 kN

apply factor from above

Wf= 15.0*10.62
= 159.30 kN

so maximum shear is as above

Ultimate Qu= Wf*11/12
= (159.30*11)/12
= 146.03 kN

and for allowable value

allowable max shear= 146.03/1.50
= 97.35 kN

Shear values	**Ultimate**	**146.03 kN**
	Allowable	**97.35 kN**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016		
	Element :	12m X-Beam Results		
	Job Number :	W0224	By : mrb	Date: Dec 16
	Document No :	001A	Checked: mmr	Date: Dec 16

ALAN WHITE DESIGN

12.0m X-BEAM

Loadcase No.		Ultimate Moment	Allowable Moment
1	UDL	448.20	298.80
2	Point	431.10	287.40
3	Third	476.40	317.60
4	Quarter	513.90	342.60

Loadcase No.		Ultimate Shear	Allowable Shear
5	End Shear	146.03	97.35

Max Allowable Moment = 287.40 kNm

Max Allowable Shear = 97.00 kN

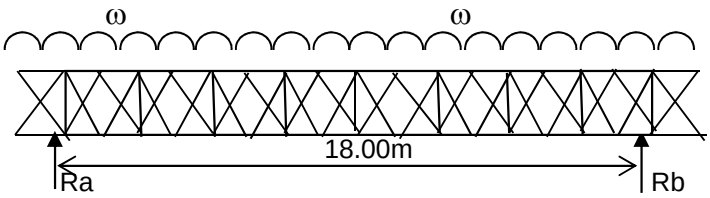
CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			AWD ALAN WHITE DESIGN
	Element :	18m X-Beam Results			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

18m X-Beam Results

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			ALAN WHITE DESIGN
	Element :	18m X-Beam Load Combination 1			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Load Comb. 1 UDL load 10kN/m applied along beam

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	5.79	2.87
	Shear	V_{Rd}	143.12	14.93	9.59
	Tension	$N_{o,Rd}$	471.94	131.02	3.60
	Compression	$N_{b,Rd}$	470.25	394.20	1.19
	Deflection	d	180.00	73.03	2.46
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	0.90
Vertical	Moment	$M_{c,Rd}$	0.87	0.21	4.13
	Shear	V_{Rd}	22.67	0.29	77.12
	Tension	$N_{o,Rd}$	86.77	2.67	32.50
	Compression	$N_{b,Rd}$	84.30	36.68	2.30
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	1.59
Diagonal	Tension	$N_{o,Rd}$	83.06	62.93	1.32
	Compression	$N_{b,Rd}$	82.23	76.78	1.07
				Factor	**0.90**



Max Moment= $WL^2/8$

so for ultimate condition

W= 1.5*10
15.00 kN

apply factor from above

Wf= 15*0.90
= 13.50 kN

so maximum moment is as above

Ultimate Mu= Wf*18^2/8
= (13.50*18^2)/8
= 546.75 kNm

and for allowable value

allowable max moment= 546.75/1.50
= 364.50 kNm

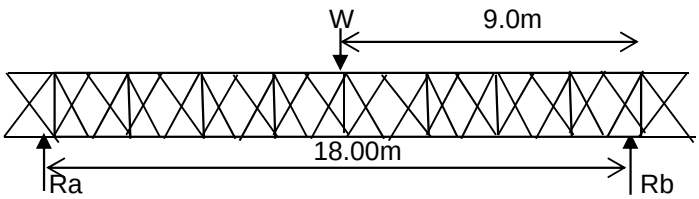
Moment values	**Ultimate**	**546.75 kNm**
	Allowable	**364.50 kNm**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016		
	Element :	18m X-Beam Load Combination 2		
	Job Number :	W0224	By : mrb	Date: Dec 16
	Document No :	001A	Checked: mmr	Date: Dec 16

ALAN WHITE DESIGN

Load Comb. 2 Point load 10kN load applied at midspan of beam

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	0.83	20.00
	Shear	V_{Rd}	143.12	2.00	71.56
	Tension	$N_{o,Rd}$	471.94	25.01	18.87
	Compression	$N_{b,Rd}$	470.25	52.07	9.03
	Deflection	d	180.00	9.11	19.76
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	6.67
Vertical	Moment	$M_{c,Rd}$	0.87	0.02	48.20
	Shear	V_{Rd}	22.67	0.03	872.08
	Tension	$N_{o,Rd}$	86.77	0.40	215.84
	Compression	$N_{b,Rd}$	84.30	2.74	30.74
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	20.34
Diagonal	Tension	$N_{o,Rd}$	83.06	5.55	14.97
	Compression	$N_{b,Rd}$	82.23	6.12	13.44
				Factor	**6.67**



Max Moment= WL/4

so for ultimate condition

W= 1.50*10
= 15.00 kN

apply factor from above

Wf= 15*6.67
= 100.05 kN

so maximum moment is as above

Ultimate Mu= Wf*18/4
= 100.05*18/4
= 450.23 kNm

and for allowable value

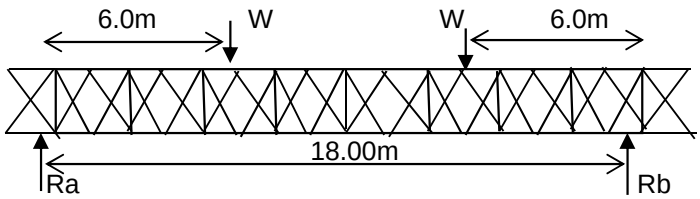
allowable max moment= 450.23/1.50
= 300.15 kNm

Moment values	**Ultimate**	**450.23 kNm**
	Allowable	**300.15 kNm**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			ALAN WHITE DESIGN
	Element :	18m X-Beam Load Combination 3			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Load Comb. 3 PL at third points 10kN load applied at each of the two third points

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	0.83	20.05
	Shear	V_{Rd}	143.12	2.05	69.68
	Tension	$N_{o,Rd}$	471.94	21.78	21.67
	Compression	$N_{b,Rd}$	470.25	67.91	6.92
	Deflection	d	180.00	12.89	13.96
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	5.46
Vertical	Moment	$M_{c,Rd}$	0.87	0.03	27.12
	Shear	V_{Rd}	22.67	0.05	503.87
	Tension	$N_{o,Rd}$	86.77	0.79	109.83
	Compression	$N_{b,Rd}$	84.30	4.67	18.04
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	11.76
Diagonal	Tension	$N_{o,Rd}$	83.06	9.61	8.64
	Compression	$N_{b,Rd}$	82.23	10.59	7.76
				Factor	**5.46**



Max Moment= WL/3

so for ultimate condition

W= 1.50*10
15.00 kN

apply factor from above

Wf= 15.00*5.46
= 81.90 kN

so maximum moment is as above

Ultimate Mu= Wf*L/3
= (81.90*18)/3
= 491.40 kNm

and for allowable value

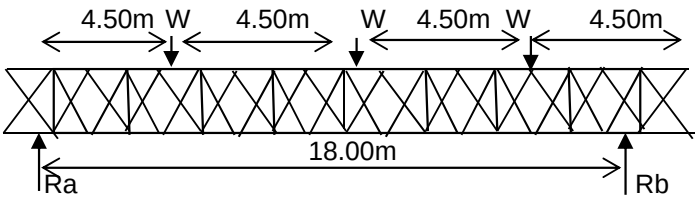
allowable max moment= 491.40/1.50
= 327.60 kNm

Moment values	**Ultimate**	**491.40 kNm**
	Allowable	**327.60 kNm**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			ALAN WHITE DESIGN
	Element :	18m X-Beam Load Combination 4			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Load Comb. 4 Load at quarter points
10kN load applied at each of the three quarter points

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	1.14	14.60
	Shear	V_{Rd}	143.12	2.89	49.52
	Tension	$N_{o,Rd}$	471.94	35.02	13.48
	Compression	$N_{b,Rd}$	470.25	94.88	4.96
	Deflection	d	180.00	17.50	10.29
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	3.92
Vertical	Moment	$M_{c,Rd}$	0.87	0.05	18.86
	Shear	V_{Rd}	22.67	0.06	354.28
	Tension	$N_{o,Rd}$	86.77	0.93	93.30
	Compression	$N_{b,Rd}$	84.30	6.61	12.75
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	8.26
Diagonal	Tension	$N_{o,Rd}$	83.06	13.60	6.11
	Compression	$N_{b,Rd}$	82.23	14.99	5.49
				Factor	**3.92**



Max Moment= WL/2

so for ultimate condition

W= 1.50*10
15.00 kN

apply factor from above

Wf= 15.00*3.92
= 58.80 kN

so maximum moment is as above

Ultimate Mu= Wf*L/2
= (58.80*18)/2
= 529.20 kNm

and for allowable value

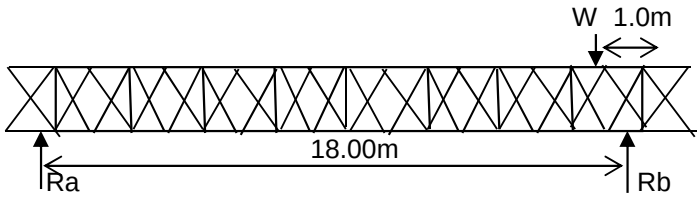
allowable max moment= 529.20/1.50
= 352.80 kNm

Moment values	**Ultimate**	**529.20 kNm**
	Allowable	**352.80 kNm**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			AWD ALAN WHITE DESIGN
	Element :	18m X-beam Load Combination 5			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Load Comb. 5 End Shear 10kN load applied at a 1.0m distance from the support

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	0.76	21.84
	Shear	V_{Rd}	143.12	2.21	64.79
	Tension	$N_{o,Rd}$	471.94	4.08	115.67
	Compression	$N_{b,Rd}$	470.25	15.19	30.96
	Deflection	d	180.00	2.76	65.22
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	14.11
Vertical	Moment	$M_{c,Rd}$	0.87	0.02	51.04
	Shear	V_{Rd}	22.67	0.02	944.75
	Tension	$N_{o,Rd}$	86.77	0.27	321.36
	Compression	$N_{b,Rd}$	84.30	4.45	18.96
	Combined Axial	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	14.70
Diagonal	Tension	$N_{o,Rd}$	83.06	7.09	11.72
	Compression	$N_{b,Rd}$	82.23	9.75	8.43
				Factor	**8.43**



Max Shear Rb= W*17/18

so for ultimate condition

W= 1.50*10.0
15.00 kN

apply factor from above

Wf= 15.00*8.43
= 126.45 kN

so maximum shear is as above

Ultimate Qu= Wf*17/18
= (126.45*17)/18
= 119.43 kN

and for allowable value

allowable max shear= 119.43/1.50
= 79.62 kN

Shear values	**Ultimate**	**119.43 kN**
	Allowable	**79.62 kN**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016		
	Element :	18m X-Beam Results		
	Job Number :	W0224	By : mrb	Date: Dec 16
	Document No :	001A	Checked: mmr	Date: Dec 16

ALAN WHITE DESIGN

18.0m X-BEAM

Loadcase No.		Ultimate Moment	Allowable Moment
1	UDL	546.75	364.50
2	Point	450.23	300.15
3	Third	491.40	327.60
4	Quarter	529.20	352.80

Loadcase No.		Ultimate Shear	Allowable Shear
5	End Shear	119.43	79.62

Max Allowable Moment = 300.00 kNm

Max Allowable Shear = 79.50 kN

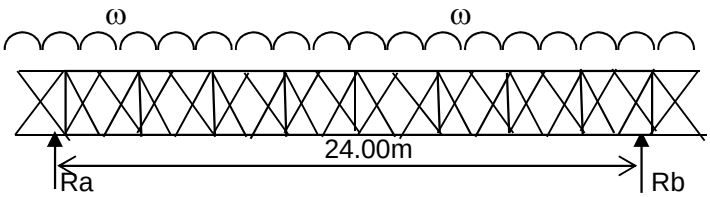
CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			AWD ALAN WHITE DESIGN
	Element :	24m X-Beam Results			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

24m X-Beam Results

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			ALAN WHITE DESIGN
	Element :	24m X-Beam Results			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Load Comb. 1 UDL load 10kN/m applied along beam

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	7.91	2.10
	Shear	V_{Rd}	143.12	20.15	7.10
	Tension	$N_{o,Rd}$	471.94	240.51	1.96
	Compression	$N_{b,Rd}$	470.25	722.81	0.65
	Deflection	d	240.00	213.85	1.12
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	0.52
Vertical	Moment	$M_{c,Rd}$	0.87	0.29	2.96
	Shear	V_{Rd}	22.67	0.41	55.03
	Tension	$N_{o,Rd}$	86.77	5.19	16.72
	Compression	$N_{b,Rd}$	84.30	47.92	1.76
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	1.19
Diagonal	Tension	$N_{o,Rd}$	83.06	87.60	0.95
	Compression	$N_{b,Rd}$	82.23	104.38	0.79
				Factor	**0.52**



Max Moment= $WL^2/8$

so for ultimate condition

W= 1.5*10
15.00 kN

apply factor from above

Wf= 15*0.52
= 7.80 kN

so maximum moment is as above

Ultimate Mu= Wf*24^2/8
= (7.80*24^2)/8
= 561.60 kNm

and for allowable value

allowable max moment= 561.60/1.50
= 374.40 kNm

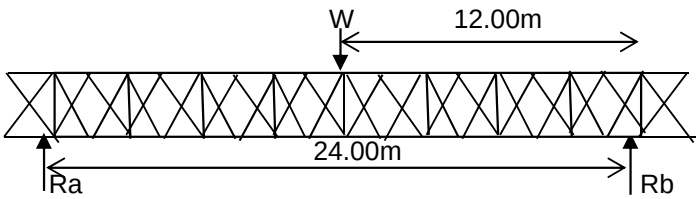
Moment values	**Ultimate**	**561.60 kNm**
	Allowable	**374.40 kNm**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016		
	Element :	24m X-Beam Results		
	Job Number :	W0224	By : mrb	Date: Dec 16
	Document No :	001A	Checked: mmr	Date: Dec 16

ALAN WHITE DESIGN

Load Comb. 2 Point load 10kN load applied at midspan of beam

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	0.86	19.30
	Shear	V_{Rd}	143.12	1.97	72.65
	Tension	$N_{o,Rd}$	471.94	35.55	13.28
	Compression	$N_{b,Rd}$	470.25	75.67	6.21
	Deflection	d	240.00	20.62	11.64
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	4.98
Vertical	Moment	$M_{c,Rd}$	0.87	0.02	43.38
	Shear	V_{Rd}	22.67	0.03	781.87
	Tension	$N_{o,Rd}$	86.77	0.75	115.69
	Compression	$N_{b,Rd}$	84.30	2.96	28.51
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	18.66
Diagonal	Tension	$N_{o,Rd}$	83.06	6.10	13.62
	Compression	$N_{b,Rd}$	82.23	6.85	12.01
				Factor	**4.98**



Max Moment= WL/4

so for ultimate condition

W= 1.50*10
= 15.00 kN

apply factor from above

Wf= 15*4.98
= 74.70 kN

so maximum moment is as above

Ultimate Mu= Wf*24/4
= 74.70*24/4
= 448.20 kNm

and for allowable value

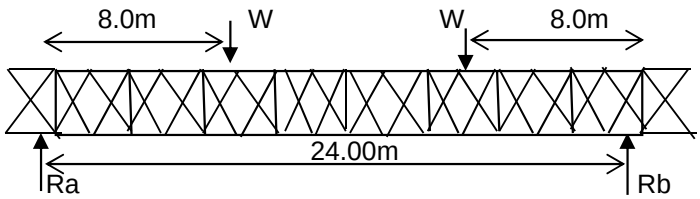
allowable max moment= 448.20/1.50
= 298.80 kNm

Moment values	**Ultimate**	**448.20 kNm**
	Allowable	**298.80 kNm**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			ALAN WHITE DESIGN
	Element :	24m X-Beam Results			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Load Comb. 3 PL at third points 10kN load applied at each of the two third points

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	0.87	19.19
	Shear	V_{Rd}	143.12	2.18	65.56
	Tension	$N_{o,Rd}$	471.94	31.62	14.93
	Compression	$N_{b,Rd}$	470.25	96.87	4.85
	Deflection	d	240.00	29.44	8.15
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	4.07
Vertical	Moment	$M_{c,Rd}$	0.87	0.03	25.52
	Shear	V_{Rd}	22.67	0.05	472.38
	Tension	$N_{o,Rd}$	86.77	0.93	93.30
	Compression	$N_{b,Rd}$	84.30	4.89	17.26
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	11.18
Diagonal	Tension	$N_{o,Rd}$	83.06	10.15	8.18
	Compression	$N_{b,Rd}$	82.23	11.29	7.28
				Factor	**4.07**



Max Moment= WL/3

so for ultimate condition

W= 1.50*10
15.00 kN

apply factor from above

Wf= 15.00*4.07
= 61.05 kN

so maximum moment is as above

Ultimate Mu= Wf*L/3
= (61.05*24)/3
= 488.40 kNm

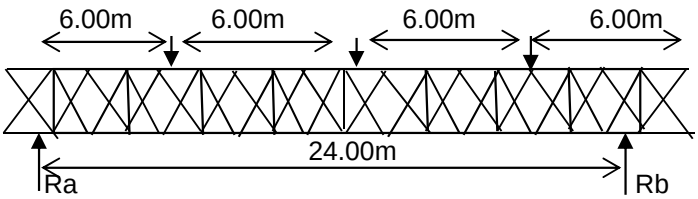
and for allowable value

allowable max moment= 488.40/1.50
= 325.60 kNm

Moment values	**Ultimate**	**488.40 kNm**
	Allowable	**325.60 kNm**

Load Comb. 4 Load at quarter points
10kN load applied at each of the three quarter points

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	1.20	13.81
	Shear	V_{Rd}	143.12	3.03	47.31
	Tension	$N_{o,Rd}$	471.94	52.29	9.03
	Compression	$N_{b,Rd}$	470.25	139.89	3.36
	Deflection	d	240.00	40.81	5.88
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	2.83
Vertical	Moment	$M_{c,Rd}$	0.87	0.05	18.08
	Shear	V_{Rd}	22.67	0.07	338.42
	Tension	$N_{o,Rd}$	86.77	1.84	47.16
	Compression	$N_{b,Rd}$	84.30	6.75	12.49
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	8.03
Diagonal	Tension	$N_{o,Rd}$	83.06	14.19	5.85
	Compression	$N_{b,Rd}$	82.23	14.73	5.58
				Factor	**2.83**



Max Moment= WL/2

so for ultimate condition

W= 1.50*10
15.00 kN

apply factor from above

Wf= 15.00*2.83
= 42.45 kN

so maximum moment is as above

Ultimate Mu= Wf*L/2
= (42.45*24)/2
= 509.40 kNm

and for allowable value

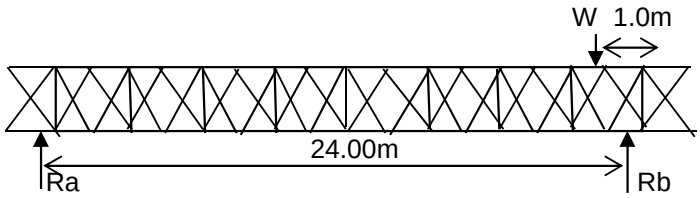
allowable max moment= 509.40/1.50
= 339.60 kNm

Moment values	**Ultimate**	**509.40 kNm**
	Allowable	**339.60 kNm**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			AWD ALAN WHITE DESIGN
	Element :	24m X-Beam Results			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Load Comb. 5 End Shear 10kN load applied at a 1.0m distance from the support

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	0.82	20.27
	Shear	V_{Rd}	143.12	2.35	60.80
	Tension	$N_{o,Rd}$	471.94	6.12	77.12
	Compression	$N_{b,Rd}$	470.25	22.39	21.00
	Deflection	d	240.00	6.59	36.42
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	11.32
Vertical	Moment	$M_{c,Rd}$	0.87	0.02	45.67
	Shear	V_{Rd}	22.67	0.03	839.78
	Tension	$N_{o,Rd}$	86.77	0.32	271.15
	Compression	$N_{b,Rd}$	84.30	4.77	17.68
	Combined Axial	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	13.58
Diagonal	Tension	$N_{o,Rd}$	83.06	7.78	10.68
	Compression	$N_{b,Rd}$	82.23	10.52	7.82
				Factor	**7.82**



Max Shear Rb= W*23/24

so for ultimate condition

W= 1.50*10.0
15.00 kN

apply factor from above

Wf= 15.00*7.82
= 117.30 kN

so maximum shear is as above

Ultimate Qu= Wf*23/24
= (117.30*23)/24
= 112.41 kN

and for allowable value

allowable max shear= 112.41/1.50
= 74.94 kN

Shear values	**Ultimate**	**112.41 kN**
	Allowable	**74.94 kN**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016		
	Element :	24m X-Beam Results		
	Job Number :	W0224	By : mrb	Date: Dec 16
	Document No :	001A	Checked: mmr	Date: Dec 16

ALAN WHITE DESIGN

24.0m X-BEAM

Loadcase No.		Ultimate Moment	Allowable Moment
1	UDL	561.60	374.40
2	Point	448.20	298.80
3	Third	488.40	325.60
4	Quarter	509.40	339.60

Loadcase No.		Ultimate Shear	Allowable Shear
5	End Shear	112.41	74.94

Max Allowable Moment = 298.50 kNm

Max Allowable Shear = 74.50 kN

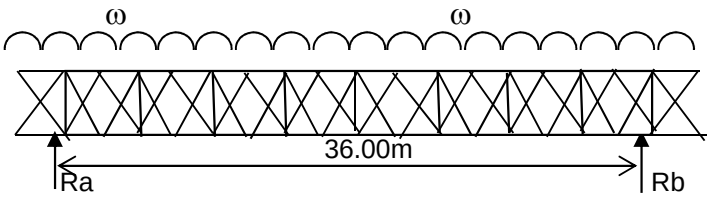
CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			AWD ALAN WHITE DESIGN
	Element :	36m X-Beam Results			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

36m X-Beam Results

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			ALAN WHITE DESIGN
	Element :	36m X-Beam Results			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Load Comb. 1 UDL load 10kN/m applied along beam

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	12.30	1.35
	Shear	V_{Rd}	143.12	30.70	4.66
	Tension	$N_{o,Rd}$	471.94	558.01	0.85
	Compression	$N_{b,Rd}$	470.25	1,675.75	0.28
	Deflection	d	300.00	1,034.00	0.29
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	0.24
Vertical	Moment	$M_{c,Rd}$	0.87	0.46	1.88
	Shear	V_{Rd}	22.67	0.65	35.05
	Tension	$N_{o,Rd}$	86.77	12.00	7.23
	Compression	$N_{b,Rd}$	84.30	69.36	1.22
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	0.80
Diagonal	Tension	$N_{o,Rd}$	83.06	136.73	0.61
	Compression	$N_{b,Rd}$	82.23	160.43	0.51
				Factor	**0.24**



Max Moment= $WL^2/8$

so for ultimate condition

W= 1.5*10
15.00 kN

apply factor from above

Wf= 15*0.24
= 3.60 kN

so maximum moment is as above

Ultimate Mu= Wf*36^2/8
= (3.60*36^2)/8
= 583.20 kNm

and for allowable value

allowable max moment= 583.20/1.50
= 388.80 kNm

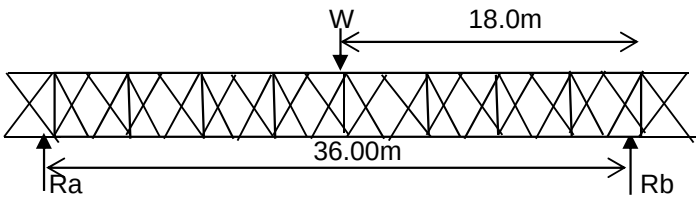
Moment values	**Ultimate**	**583.20 kNm**
	Allowable	**388.80 kNm**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016		
	Element :	36m X-Beam Results		
	Job Number :	W0224	By : mrb	Date: Dec 16
	Document No :	001A	Checked: mmr	Date: Dec 16

ALAN WHITE DESIGN

Load Comb. 2 Point load 10kN load applied at midspan of beam

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	0.89	18.65
	Shear	V_{Rd}	143.12	1.90	75.33
	Tension	$N_{o,Rd}$	471.94	58.91	8.01
	Compression	$N_{b,Rd}$	470.25	129.00	3.65
	Deflection	d	300.00	72.70	4.13
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	3.18
Vertical	Moment	$M_{c,Rd}$	0.87	0.02	36.15
	Shear	V_{Rd}	22.67	0.03	666.89
	Tension	$N_{o,Rd}$	86.77	1.03	84.24
	Compression	$N_{b,Rd}$	84.30	3.36	25.06
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	16.09
Diagonal	Tension	$N_{o,Rd}$	83.06	7.18	11.57
	Compression	$N_{b,Rd}$	82.23	8.20	10.02
				Factor	**3.18**



Max Moment= WL/4

so for ultimate condition

W= 1.50*10
= 15.00 kN

apply factor from above

Wf= 15*3.18
= 47.70 kN

so maximum moment is as above

Ultimate Mu= Wf*36/4
= 47.70*36/4
= 429.30 kNm

and for allowable value

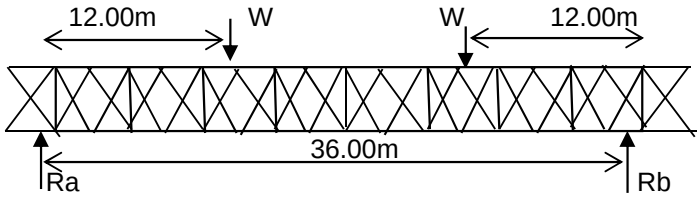
allowable max moment= 429.30/1.50
= 286.20 kNm

Moment values	**Ultimate**	**429.30 kNm**
	Allowable	**286.20 kNm**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			ALAN WHITE DESIGN
	Element :	36m X-Beam Results			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Load Comb. 3 PL at third points 10kN load applied at each of the two third points

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	0.99	16.82
	Shear	V_{Rd}	143.12	2.44	58.59
	Tension	$N_{o,Rd}$	471.94	53.20	8.87
	Compression	$N_{b,Rd}$	470.25	161.58	2.91
	Deflection	d	300.00	102.48	2.93
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	2.57
Vertical	Moment	$M_{c,Rd}$	0.87	0.04	22.83
	Shear	V_{Rd}	22.67	0.05	427.81
	Tension	$N_{o,Rd}$	86.77	1.35	64.27
	Compression	$N_{b,Rd}$	84.30	5.19	16.23
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	10.32
Diagonal	Tension	$N_{o,Rd}$	83.06	11.23	7.40
	Compression	$N_{b,Rd}$	82.23	12.70	6.48
				Factor	**2.57**



Max Moment= WL/3

so for ultimate condition

W= 1.50*10
15.00 kN

apply factor from above

Wf= 15.00*2.57
= 38.55 kN

so maximum moment is as above

Ultimate Mu= Wf*L/3
= (38.55*36)/3
= 462.60 kNm

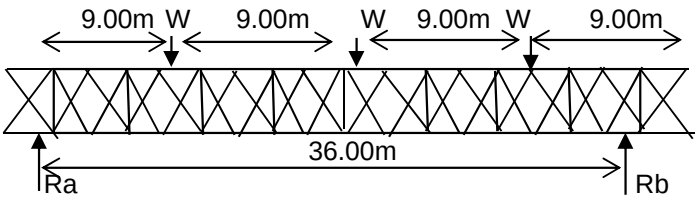
and for allowable value

allowable max moment= 462.60/1.50
= 308.40 kNm

Moment values	**Ultimate**	**462.60 kNm**
	Allowable	**308.40 kNm**

Load Comb. 4 Load at quarter points
10kN load applied at each of the three quarter points

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	1.33	12.46
	Shear	V_{Rd}	143.12	3.29	43.46
	Tension	$N_{o,Rd}$	471.94	83.64	5.64
	Compression	$N_{b,Rd}$	470.25	226.00	2.08
	Deflection	d	300.00	136.47	2.20
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	1.85
Vertical	Moment	$M_{c,Rd}$	0.87	0.05	16.69
	Shear	V_{Rd}	22.67	0.07	314.92
	Tension	$N_{o,Rd}$	86.77	1.65	52.59
	Compression	$N_{b,Rd}$	84.30	7.03	12.00
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	7.60
Diagonal	Tension	$N_{o,Rd}$	83.06	15.25	5.44
	Compression	$N_{b,Rd}$	82.23	17.19	4.78
				Factor	**1.85**



Max Moment= WL/2

so for ultimate condition

W= 1.50*10
15.00 kN

apply factor from above

Wf= 15.00*1.85
= 27.75 kN

so maximum moment is as above

Ultimate Mu= Wf*L/2
= (27.75*36)/2
= 499.50 kNm

and for allowable value

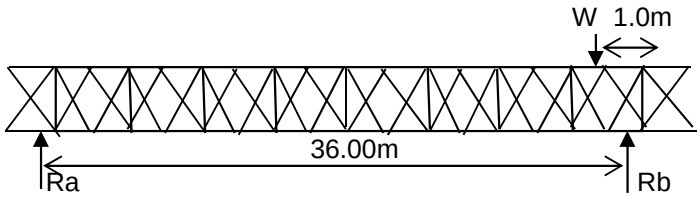
allowable max moment= 499.50/1.50
= 333.00 kNm

Moment values	**Ultimate**	**499.50 kNm**
	Allowable	**333.00 kNm**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			ALAN WHITE DESIGN
	Element :	36m X-Beam Results			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Load Comb. 5 End Shear 10kN load applied at a 1.0m distance from the support

Element	Action	Formula	Ultimate	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	16.60	0.93	17.87
	Shear	V_{Rd}	143.12	2.62	54.61
	Tension	$N_{o,Rd}$	471.94	13.16	35.86
	Compression	$N_{b,Rd}$	470.25	44.06	10.67
	Deflection	d	300.00	27.19	11.03
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	7.23
Vertical	Moment	$M_{c,Rd}$	0.87	0.02	36.15
	Shear	V_{Rd}	22.67	0.03	687.09
	Tension	$N_{o,Rd}$	86.77	0.46	188.63
	Compression	$N_{b,Rd}$	84.30	5.23	16.12
	Combined Axial	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$		1.00	11.94
Diagonal	Tension	$N_{o,Rd}$	83.06	9.03	9.20
	Compression	$N_{b,Rd}$	82.23	11.94	6.89
				Factor	**6.89**



Max Shear Rb= W*29/30

so for ultimate condition

W= 1.50*10.0
15.00 kN

apply factor from above

Wf= 15.00*6.89
= 103.35 kN

so maximum shear is as above

Ultimate Qu= Wf*35/36
= (103.35*35)/36
= 100.48 kN

and for allowable value

allowable max shear= 100.48/1.50
= 66.99 kN

Shear values	**Ultimate**	**100.48 kN**
	Allowable	**66.99 kN**

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016		
	Element :	36m X-Beam Results		
	Job Number :	W0224	By : mrb	Date: Dec 16
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36.0m X-BEAM

Loadcase No.		Ultimate Moment	Allowable Moment
1	UDL	583.20	388.80
2	Point	429.30	286.20
3	Third	462.60	308.40
4	Quarter	499.50	333.00

Loadcase No.		Ultimate Shear	Allowable Shear
5	End Shear	100.48	66.99

Max Allowable Moment = 286.00 kNm

Max Allowable Shear = 70.00 kN

CALCULATION SHEET	Project :	Apollo 1.5m X-beam 2016			AWD ALAN WHITE DESIGN
	Element :	Overall X-Beam Results			
	Job Number :	W0224	By : mrb	Date: Dec 16	
	Document No :	001A	Checked: mmr	Date: Dec 16	

Overall X-Beam Results

Load case 1 : UDL

1.5m X-BEAM	
Loadcase 1 Length (m)	**Ultimate Moment**
12	448.20
18	546.75
24	561.60
36	583.20

Average 534.94 kNm
Minimum 448.20 kNm

Load case 2 : Central Point Load

1.5m X-BEAM	
Loadcase 2 Length (m)	**Ultimate Moment**
12	431.10
18	450.23
24	448.20
36	429.30

Average 440.66 kNm
Minimum 431.10 kNm

Load case 3 : Two Point Loads at Third Points

1.5m X-BEAM	
Loadcase 3 Length (m)	**Ultimate Moment**
12	476.40
18	491.40
24	488.40
36	462.60

Average 483.90 kNm
Minimum 476.40 kNm

Load case 4 : Three Point Loads at Quarter Points

1.5m X-BEAM	
Loadcase 4 Length (m)	**Ultimate Moment**
12	513.90
18	529.20
24	509.40
36	499.50

Average	521.55 kNm
Minimum	513.90 kNm

Load case 5 : Shear

1.5m X-BEAM	
Loadcase 5 Length (m)	**Ultimate Shear**
12	146.03
18	119.43
24	112.41
36	100.48

Average	132.73 kN
Minimum	119.43 kN

Overall Graded Results for Allowable Working Loads on a 1.5m X-Beam

For simply supported Apollo1.5m X-BEAM with a compression chord restraint at 1.0m intervals

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Test Results

	Span (m)			
	12	18	24	36
Allowable Moment	287.4	300.0	298.5	286.0
Allowable Shear (Load on Vertical)	97.0	79.5	74.5	67.0

Allowable loads for load distributions from results

Type of Load		Clear span (m)			
		12	18	24	36
Uniformly Distributed load	kN/m	16.0	7.4	4.1	1.8
Total UDL	kN	191.6	133.3	99.5	63.6
Single point load (mid Point)	kN	95.8	66.7	49.8	31.8
Two point loads (third points)	Each kN	71.9	50.0	37.3	23.8
Three point loads (quarter points)	Each kN	47.9	33.3	24.9	15.9

Extrapolated Allowable loads for load distributions

Type of Load		Clear span (m)																
		11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Uniformly Distributed load	kN/m	17.6	16.0	13.6	11.7	10.2	9.0	8.0	7.4	6.6	6.0	5.4	4.9	4.5	4.1	3.7	3.4	3.1
Total UDL	kN	194.0	191.6	176.9	164.2	153.3	143.8	135.3	133.3	125.7	119.4	113.7	108.5	103.8	99.5	91.5	88.0	84.7
Single point load (mid Point)	kN	104.5	95.8	88.5	82.1	76.7	71.9	67.6	66.7	62.8	59.7	56.9	54.3	51.9	49.8	45.8	44.0	42.4
Two point loads (third points)	Each kN	78.4	71.9	66.3	61.6	57.5	53.9	50.7	50.0	47.1	44.8	42.6	40.7	38.9	37.3	34.3	33	31.8
Three point loads (quarter points)	Each kN	52.3	47.9	44.2	41.1	38.3	35.9	33.8	33.3	31.4	29.9	28.4	27.1	26.0	24.9	22.9	22	21.2

Type of Load		Clear span (m)								
		28	29	30	31	32	33	34	35	36
Uniformly Distributed load	kN/m	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.9	2
Total UDL	kN	81.7	78.9	76.3	73.8	71.5	69.3	67.3	65.4	64
Single point load (mid Point)	kN	40.9	39.4	38.1	36.9	35.8	34.7	33.6	32.7	32
Two point loads (third points)	Each kN	30.6	29.6	28.6	37.7	26.8	26.0	25.2	24.5	24
Three point loads (quarter points)	Each kN	20.4	19.7	19.1	18.5	17.9	17.3	16.8	16.3	16

Notes:

1. This table is provided as a guide only and assume all loads are applied at nodes. All scaffolds and structures should be checked by a qualified structural engineer.
2. Maximum capacity of a point load mid way between nodes is 15kN but overall buckling of the top chord should be checked if loads are placed other than at restrained nodes. Compression chord restraint required at 1.0m c/c
3. Factor of Safety = 1.65 (= 1.5*1.1 (material factor))
4. Calculations as per BS EN 1999-1-1
5. For design purposes the allowable bending moment is 282.50kNm and the allowable shear is 66.50kN.

Graph Summary of Allowable Working Loads for a 1.5m X-Beam to BS EN 1999-1-1

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